Attempted introduction of the endangered Green and Golden Bell Frog to Long Reef Golf Course: a step towards recovery?

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ABSTRACT

The Green and Golden Bell Frog *Litoria aurea* is threatened with extinction, but generally occurs in disturbed sites and has successfully colonized some sites that are essentially artificial. It should therefore be possible to promote recovery of the species by increasing the availability of suitable habitat through habitat modification or creation and, where necessary, translocating individuals into these habitat areas. Apparently suitable habitat for this species had been created at Long Reef Golf Course in the northern Sydney suburb of Collaroy. We translocated approximately 9,000 captive-bred tadpoles from Taronga Zoo into these habitat areas over 7 years.

This program has not led to the establishment of a self-sustaining population of the Green and Golden Bell Frog at Long Reef Golf Course and must therefore be considered unsuccessful. It has had partial success as some released tadpoles metamorphosed into frogs, some of these developed into adults, and a few males were recorded calling. However, breeding by these introduced animals has not been recorded, and, in the absence of continuing tadpole releases, the number of bell frogs has declined to zero.

It has, however, provided a number of guidelines for future similar programs. Success with this program has been limited by fish, time of tadpole release and water temperature, and hence we recommend that future translocations of Green and Golden Bell Frog tadpoles should be carried out during spring or summer and should target ponds that are warm and fish-free. Program success was also limited by the numbers of tadpoles available for release. The lack of tadpoles for spring/summer release since the 2003/2004 breeding season has prevented evaluation of new, relatively warm ponds. Any captive-breeding program for this frog species must therefore be successful, in its own right, if it is to provide tadpoles for release. Disease is unlikely to have influenced the outcomes of this program, but should always be considered a potentially-important factor.

Key words: *Litoria aurea*, bell frog, translocation, captive-breeding

Introduction

The Green and Golden Bell Frog *Litoria aurea* is threatened with extinction, but generally occurs in disturbed sites and has successfully colonized some sites that are essentially artificial. This species is considered 'endangered' in NSW, 'vulnerable' in Victoria and 'vulnerable' nationally (Pyke and White 2001). At a few sites where it occurs, there are natural disturbances to aquatic breeding habitat such as fluctuation in water level and influx of saline water; at other sites breeding habitat is disturbed through human activities and in some cases is completely human-made (Pyke and White 2001). This species is able to forage and shelter in areas where all natural vegetation has been removed and replaced, and it can use a variety of artificial shelter sites (Pyke and White 2001).

It should therefore be possible to promote recovery of the species by increasing the availability of suitable habitat through habitat modification or creation and, where necessary, translocating individuals into these habitat areas. Having inadvertently created suitable habitat in a number of places, it should be possible to do it again (Pyke and White 2001). However, in situations where such artificial sites are too far from any other site where the species occurs for natural colonization to occur, it will also be necessary to translocate individuals of the species into any new htabitat (Pyke and White 2001).

Habitat that appeared suitable for the Green and Golden Bell Frog was created at Long Reef Golf Course, which lies adjacent to the Pacific Ocean in the northern Sydney suburb of Collaroy. Following assessment of the habitat requirements for the species (Pyke and White 2001; Pyke *et al.* 2002), ponds were developed at this site that were relatively shallow (generally <1 m) and exposed to the sun, had both emergent aquatic vegetation and open water, and were thought (at least initially) to be fish-free. This study describes the translocation of tadpoles of the Green and Golden Bell Frog into these habitat areas. Paradoxically, it is likely that this species originally occurred at Long Reef Golf Course. The Green and Golden Bell Frog was known to have occurred nearby (White and Pyke 1996), and prior to 1927 there was a freshwater wetland present in the low-lying part of the golf course. Old photographs of this wetland suggest that it would have provided habitat similar to that presently

occupied by the Green and Golden Bell Frog in near coastal locations such as Yuraygir (Goldingay and Newell 2005) and Hat Head (Pyke, unpubl.) National Parks. Most of the newly created ponds are in the previous location of this wetland. So this program could represent the development of new habitat at a site previously unoccupied or re-established habitat at a site where the species formerly occurred. In any case the bell frog was not present at the site when our program began.

In this paper we review the history of the program in terms of habitat development, frog translocation and monitoring results, and determine whether or not it has contributed to the recovery of the Green and Golden Bell Frog. In this regard, we would judge the program a complete success once a self-sustaining population of the species had become established.

Methods

All habitat modification and creation has been carried out by staff of Long Reef Golf Club, which supports and controls golf playing on the golf course. We initiated and maintained the monitoring program, with assistance from Golf Club staff.

Habitat development

Frog breeding habitat was developed on Long Reef Golf Course (Fig. 1) in stages. During 1996 and 1997, an inter-connected series of ponds was developed through a relatively low-lying area (approx. 3 m elevation) from one side of the golf course to the other (Fig. 2), as part of a program to provide water for irrigation of the golf course and to improve the quality of water runoff from nearby roads and urban development before it entered the ocean (Bradbery 1997; Warringah Council 1994). These ponds, which were not lined, were created by simply excavating the ground, planting them with a range of aquatic emergent plant species, and channeling water into the one that was furthest upstream (Peter Donkers & John Mullins, Long Reef Golf Club [LRGC], pers. comm.). Of these ponds we selected 7 (numbered between 1 and 11 on the basis of assigned numbers of nearby golf tees; Fig. 2) that were relatively small and all upstream of the largest and deepest pond (Fig. 2). In Feb 2000 pond 10 was destroyed and pond 12 created (Fig. 2; Table 1). Up until about 1927 there had been a natural freshwater wetland in about the same area, but this was destroyed when the golf course expanded from 9 to 18 holes (Jennings and

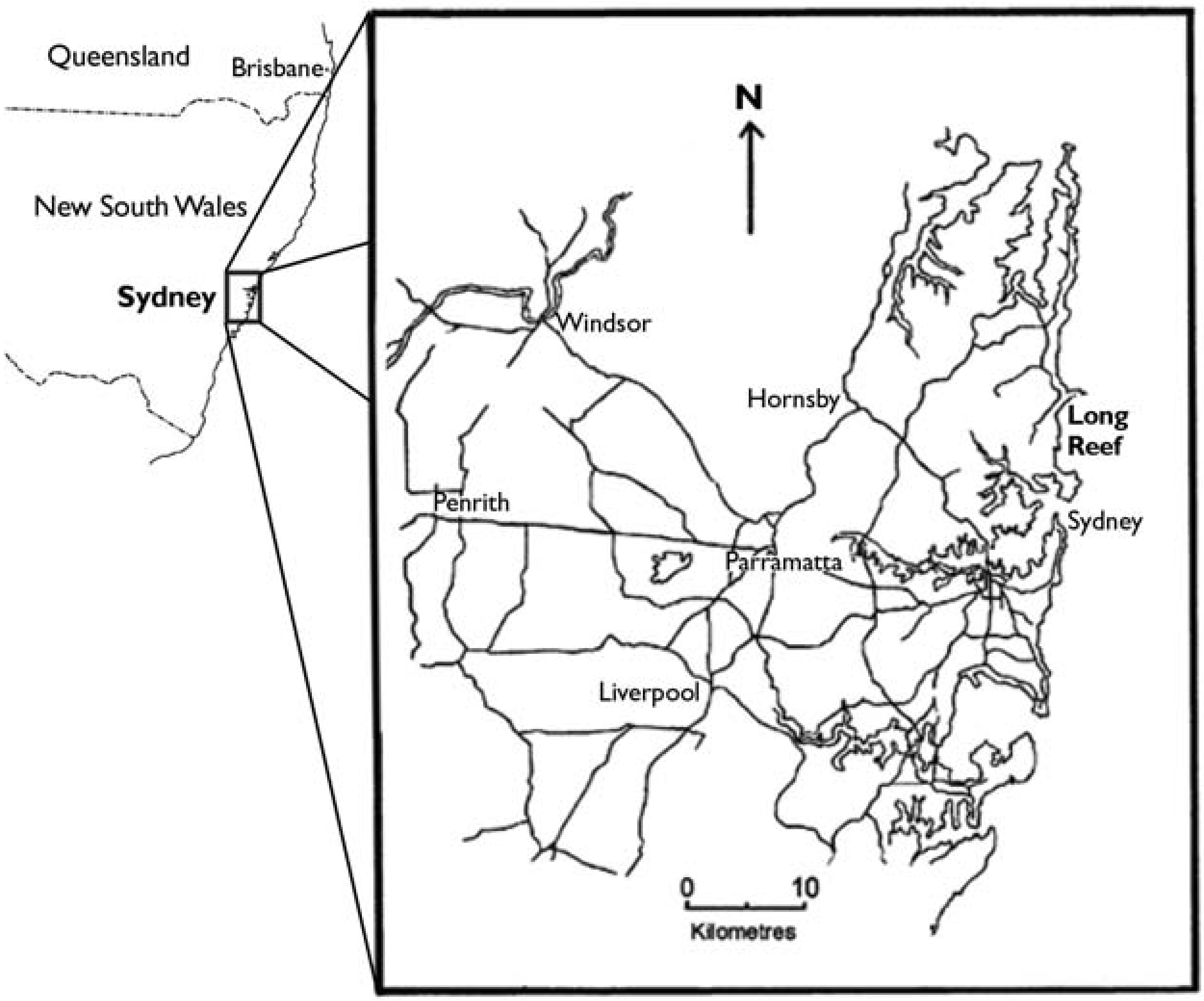

Figure 1. Location of the Long Reef study site.

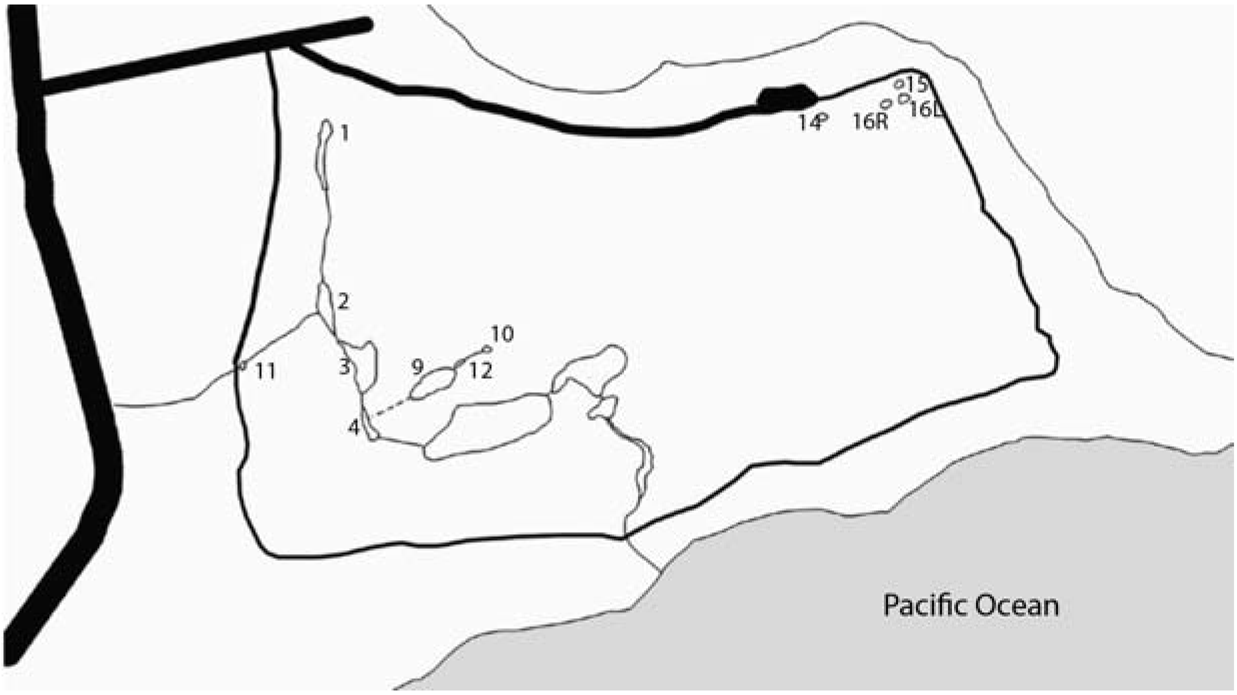

Figure 2. Map of Long Reef Golf Course and surrounding area showing locations of study ponds. Pond numbering was based on the assigned numbers of nearby golf tees or fairways.

Jennings 1991; Lanes 1989). A single pond, that was present on the golf course when pond development began in 1996, was retained (i.e., pond 9; Fig. 2). It was initially anticipated that these ponds would provide habitat for fish and birds, in addition to improving the quality of water as it passed through them, (John Mullins, LRGC, pers. comm.), but in 1997 it was decided that the ponds would become habitat for frogs rather than fish (Bradbery 1997). It was initially believed that these ponds were in fact fish free (John Mullins, LRGC, pers. comm.).

In late 1997, two additional ponds were created (ponds 14 & 15; Fig. 2), in similar fashion to the earlier ones, near the north-east corner of the golf course and about 35 m higher in elevation than the original ponds, and allowed to fill with rain water. These two ponds were, however, considerably smaller than the earlier ponds and were only about 3-5 m in diameter. They were also connected to the city water supply system, so that they could receive supplemental water if they began to dry out.

At the same time, some habitat modification was carried out around all the newly-created ponds. At some ponds, piles of medium to large rocks (i.e., up to a size that one person can comfortably lift) were placed along the edges so that at most times some rocks would be submerged and others above the water. Adjacent to some ponds there were plantings of *Lomandra* sp. and other shubs. By the end of the year all of the ponds were considered to provide suitable breeding, foraging and shelter habitat for the Green and Golden Bell Frog. Potential foraging sites included this thick low vegetation, as well as the manicured 'fairways' (i.e., mostly mown grass) and areas of relatively unmanicured 'rough' (i.e., weedy regrowth) that were part of the golf course.

Table 1. Characteristics of ponds at Long Reef Golf Course

Pond	Duration	# Shelter boards	Max. Depth	Shade
1	1997-present	11	1.0 m	None
2	1997-present	11	1.5 m	None
3	1997-present	11	2 m	None
4	1997-present	5	2 m	None
9	pre1997-present	10	2 m	None
10	1997- Feb 2000	4	20 cm	None
11	1997 - present	3	20 cm	None
12	Feb 2000 - present	4	30 cm	None
14	1997-present	4	40 cm	Partial
15	1997-present	4	60 cm	Partial
16L	Dec 2003 – present	0	40 cm	Little
16R	Dec 2003 – present	0	35 cm	Little

In response to results from the monitoring and studies elsewhere, another two ponds (16L & 16R) were created in December 2003. These ponds were built close to ponds 14 and 15 (Fig. 2) by excavating two depressions, lining these with a layer of black plastic material designed for lining garden ponds, and allowing them to fill with rain water. Piles of rocks and plantings of aquatic emergent vegetation and shrubs (including *Lomandra* sp) were developed as described above. These two ponds were positioned so that they would receive more direct sun than ponds 14 and 15.

Translocation

We translocated captive-bred animals from Taronga Zoo into the habitat areas at Long Reef Golf Course. These individuals were derived from a zoo population that was founded with stock from the natural population at Rosebery, which is the closest population of this species to Long Reef Golf Course. Translocations mostly involved tadpoles and occurred in most years between 1998 and 2003 (Table 2). Starting in 1998, we also carried out regular monitoring of the site in order to evaluate the success or otherwise of the program, and to determine appropriate habitat changes that were considered necessary to promote the program.

Prior to the commencement of this project, the senior author prepared a formal proposal, obtained a Scientific Licence from the NSW National Parks and Wildlife Service (now Department of Environment and Climate Change), and a Research Authority from the Australian Museum. The project included a program to screen tadpoles for possible chytrid infection or other disease before they could be released. This program involved inspection of tadpoles by veterinary staff at Taronga Zoo, something that could not be properly done until tadpoles were about 2-3 weeks old. Hence the tadpoles were at least 3-4 weeks old when released (see below). Tadpoles that were found to be diseased, as happened once, were not used. No initial disease screening of tadpoles or frogs already present at the release sites was carried out prior to tadpole release and no subsequent screening for disease was carried out at the study site.

The breeding program of Green and Golden Bell Frogs at Taronga Zoo began in 1994 with stock from a population at Rosebery, when this population was about to be destroyed to make way for urban development (Cogger 1993; Goldingay 1996; White and Pyke 1996). A self-sustaining captive population from this founder stock was subsequently profduced (Wright 1996). Most of the animals supplied from this breeding program were relatively advanced tadpoles (i.e., at least Gosner stage 25), including a few metamorphs (i.e., front limbs, hind limbs and tail all present), though a small number of frogs (i.e., tail disappeared) were also included (i.e., 5 on 10 Feb 2000; 1 on 4 Dec 2001). The numbers of these animals depended on how many were produced from the breeding program and hence varied considerably from breeding season to breeding season (Table 2). In all seasons the number of available animals fell far short of our desired number which was about 20,000 This number seemed feasible since the average clutch size per female per spawning is about 4,000 (Pyke and White 2001) and there were 20-30 mature females in the breeding program (Michael McFadden, Taronga Zoo, pers. comm.). It was not excessively large since the proportion of tadpoles that normally survive to become adult frogs must typically be very small. On each occasion we collected tadpoles from the Zoo in closed heavy-duty clear plastic bags filled with water, transported these by car to the golf course (a direct-line distance of about 14 km), and released them into selected ponds (Table 2). These plastic bags were first placed in the water near the edge of a pond, to allow the water temperature in the bag to equilibrate with that in the pond, and then opened up, allowing the tadpoles to swim away freely.

Tadpole releases were carried out mostly during summer, with widely varying numbers involved. There were a total of 11 tadpole releases; two in spring (i.e., Sep-Nov), seven in summer (i.e., Dec-Feb) and two in autumn (i.e., Mar-May) (Table 2). These 11 releases occurred across seven breeding seasons with 1-3 releases per season (Table 2). The numbers of tadpoles that were released during each breeding season ranged from 62 during 2002/2003 to 2298 during 2003/2004 (Table 2). There were no tadpoles available for release during the 2003/2004 and 2005/2006 breeding seasons.

Table 2. Dates and numbers of Green and Golden Bell Frog tadpoles released into ponds at Long Reef Golf Course. (Su=summer, Au=autumn, Sp=spring)

Date	Breeding season	Release season	Pond Number 1	2	3	9	10	11	14	15	16L	16R	Comment
16/01/1998	1997/1998	Su	350	200	200	200			250	250			
24/03/1999	1998/1999	Au					198	10	165	200			
04/11/1999	1999/2000	Sp	125	125					125	125			
23/12/1999	1999/2000	Su							200	200			
10/02/2000	1999/2000	Su							320	320			
22/12/2000	2000/2001	Su							500	500			Ponds dried out in Jan '01
26/02/2001	2000/2001	Su	500	500									
04/12/2001	2001/2002	Su							889	535			
09/01/2003	2002/2003	Su								62			
03/11/2003	2003/2004	Sp							387	387			
19/03/2004	2003/2004	Au							381	381	381	381	

Monitoring program

Before the monitoring program began we established artificial shelter sites around each pond. This was achieved by placing square, painted pieces of marine plywood (i.e., 12 mm thick; 60 cm on side; painted dark grey) at intervals of about 10 m around the circumference of each of the larger ponds and at intervals of about 3-4 m around the two smaller ponds that were initially present. The initial numbers of these shelter boards therefore varied between ponds (Table 2). Over subsequent years some of these boards disintegrated or disappeared and were replaced with house roofing tiles. By 2002 these artificial shelter sites were not used as part of our monitoring program (see below) and no such artificial shelter sites were placed around ponds subsequently created.

The monitoring program began a week after the first tadpole release and consisted of day-time and night-time surveys of the ponds that had been selected for animal release. These surveys were generally carried out at intervals of 1 week during the warmest months (i.e., November-April), 4 weeks during the coolest months (i.e., May-August) and 2 weeks during the intervening periods.

During diurnal surveys we focused on tadpoles, small fish and sheltering frogs, but also recorded any frogs that we saw or heard. We inspected under each artificial shelter site and, using a small, square cage, open at the top, to minimize escapees, captured frogs that were using these shelter sites. These frogs were subsequently identified, sexed, weighed and measured, before being released back under the shelter site. Adjacent to each shelter site, we carried out standardized net sweeps through the water (i.e., submerged swimming pool net, 10 sweeps, each through approximately 1.2 m of water) and identified and counted any tadpoles or small fish that were captured. In addition, we measured the snout-vent-length for up to about 10 tadpoles of each species captured per net sweep location. We also attempted to capture any Green and Golden Bell Frogs that we saw (e.g., sitting on reeds) and processed any resulting captures in the same manner. We also measured a number of physico-chemical properties of the water in each pond using a portable Yeo-kal water meter. As each pond was surveyed we placed the meter about 1m from shore and measured turbidity, pH, dissolved oxygen, salinity and water temperature.

During nocturnal surveys we censused and captured active frogs, and carried out visual counts of tadpoles and fish. Captured frogs were examined, weighed, measured and assigned to four sex/age categories (i.e., immature: snout-vent length [SVL] <48 mm; adult male: SVL$\geq$48 mm, nuptial pads present; immature female: 48 mm$\leq$SVL$<$67 mm, nuptial pads absent; adult female: SVL$\geq$67 mm, nuptial pads absent). We censused active frogs by walking around the circumference of each pond, recording the identities and numbers of any calling frogs, attempting to capture any bell frogs that we detected, and occasionally capturing other species. We censused tadpoles and fish by searching the water within about 1 m of the edge of a pond around its circumference. Using this approach we were sometimes able to record larger fish (i.e., eels) that were never captured in the net.

Results

Survival & Metamorphosis vs. season of release, # released & pond desiccation

Some of the released bell frog tadpoles survived, completed metamorphosis and subsequently grew to become adult frogs. Post release of tadpoles, we observed and captured bell frogs of all life stages from tadpole through to adult males and females. We observed low numbers of adult frogs in relation to the numbers of tadpoles released.

Tadpole releases did not yield any metamorph or immature bell frogs if they occurred during autumn, if the number released was very low, or if the ponds dried out soon after release. Following the two autumn tadpole releases (i.e., March 1999 and 2004, totaling about 2100 tadpoles; Table 2), we did not observe any metamorphs or immature bell frogs (i.e., between March and November 1999, and after March 2004). There were no bell frog tadpoles, metamorphs or immatures observed following the release of 62 tadpoles during the 2002/2003 breeding season. Tadpoles were released on 22 December 2000, but the recipient ponds had dried up completely prior to 25 January 2001 when monitoring resumed. The dryness of the soil at this latter date, relatively high temperatures and lack of rain prevailing during this period, and observations by golf course staff suggest these ponds had probably dried out by early January. No tadpoles, metamorphs or immature bell frogs were observed between this and the next tadpole release, which took place on 26 February 2001.

The following descriptions of tadpoles, immature and adult bell frogs have omitted the 1999/2000 breeding season, when there were only 7 weeks between successive tadpole releases (Table 2) and hence some possible ambiguity in terms of knowing which release to attribute any tadpoles, metamorphs or immatures. Bell frog tadpoles were captured during sweep net samples, but few were captured more than 10 weeks post release (Fig. 3). Most (80%, n=20) captures occurred within 70 days of tadpole release. Further analysis of these tadpole capture data was restricted to the 10-week periods after tadpole releases.

Metamorphosis of bell frog tadpoles peaked 20-40 days post tadpole release and almost all of the tadpoles that metamorphosed did so within about 100 days of release. The frequency distribution of days since release had a peak between 20 and 40 days and is skewed to the right, and all but one metamorph (n=13) were observed within 104 days post release (Fig. 4). A single metamorph was observed about a year after tadpole release. Analysis of these metamorph data was restricted to the 104-day periods after tadpole release.

Immature bell frogs began to be observed soon after tadpole release but peak numbers were not observed until 60-80 days post release (Fig. 5). Most (88%, n=77) were observed within 200 days post tadpole release, and a few were observed about 300-400 days post release. The frequency distribution of number of days post release for observed immatures was also skewed to the right in this case (Fig. 5). Analysis of these immature frog data was restricted to the 200-day periods after tadpole release.

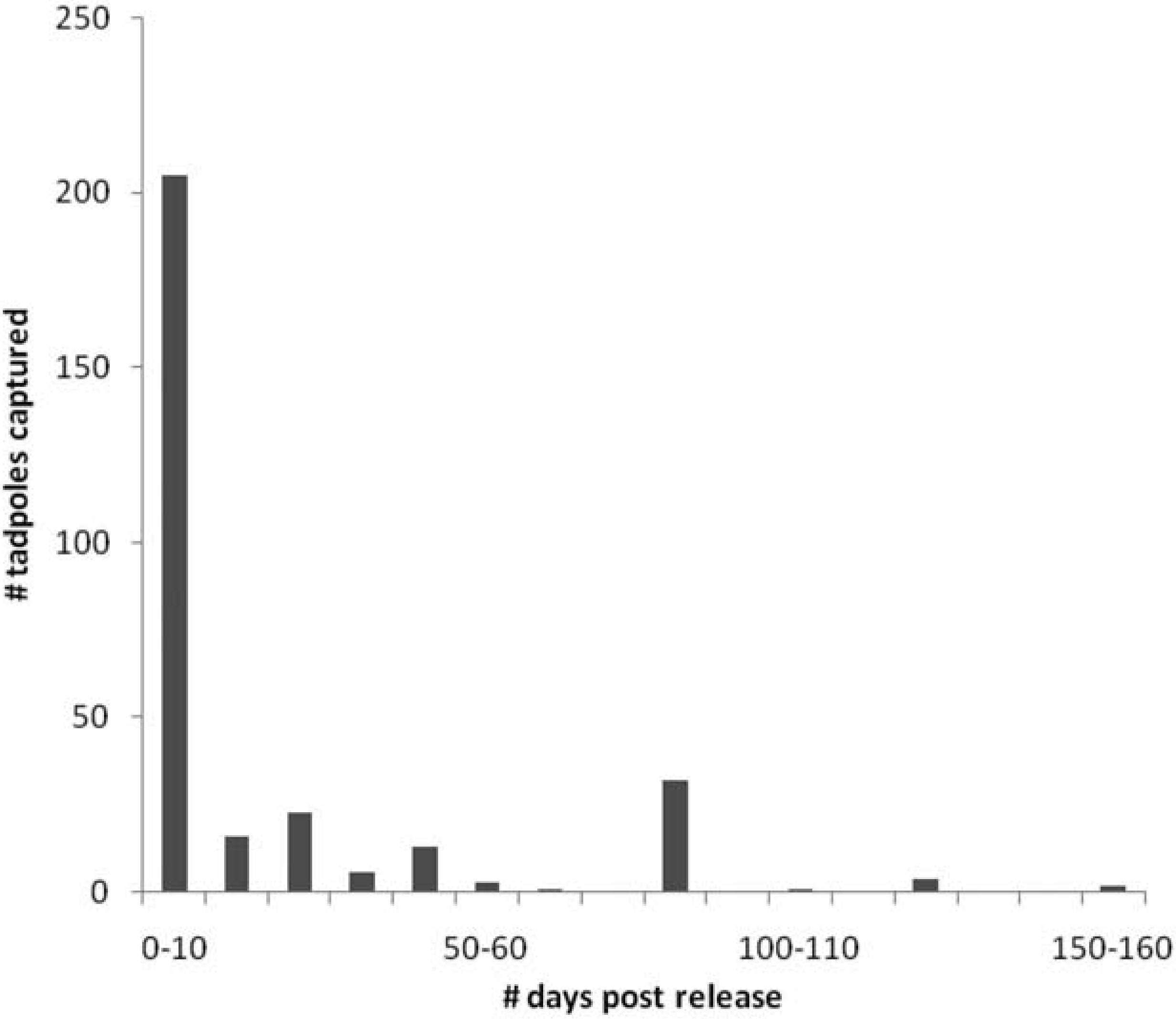

Figure 3. Number of tadpoles captured at different times (days) post-release.

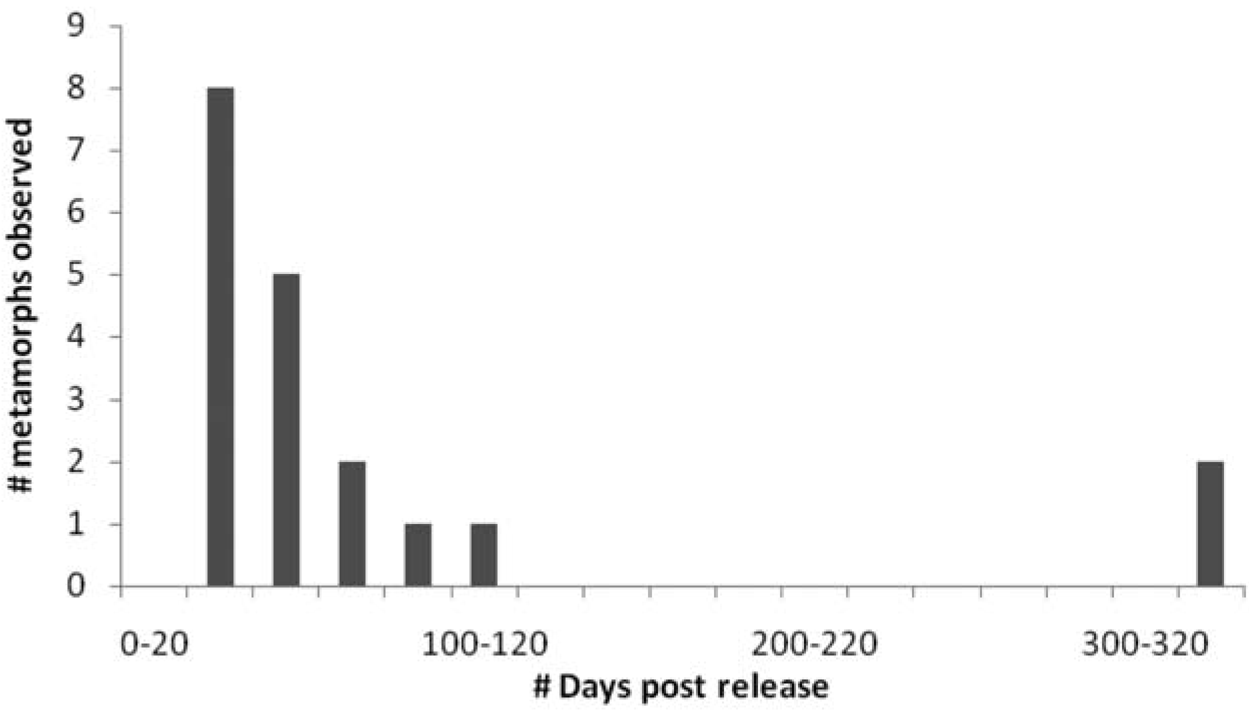

Figure 4. Number of metamorphs observed at different times (days) post-release.

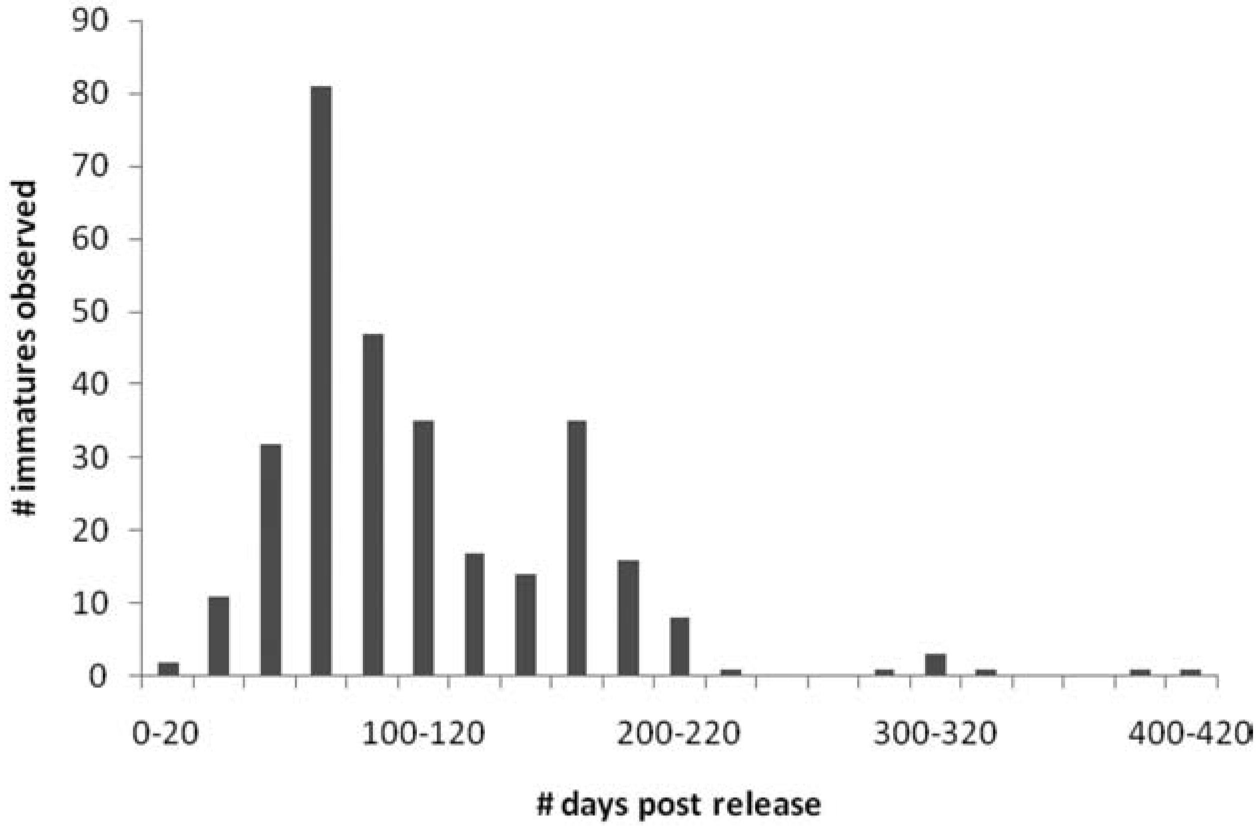

Figure 5. Number of immature frogs observed at different times (days) post-release.

Adult bell frogs began to be observed about 50 days post tadpole release, with peak numbers observed 100-150 days post release (Fig. 6). In this case the frequency distribution of days since tadpole release appeared bimodal with a second peak about a year (i.e., 350-400 days) after release (Fig. 6).

Tadpole release vs. fish

The monitoring program quickly revealed that many of the ponds contained fish when we carried out our first release of tadpoles (Rowley *et al.* 2005). Both native fish

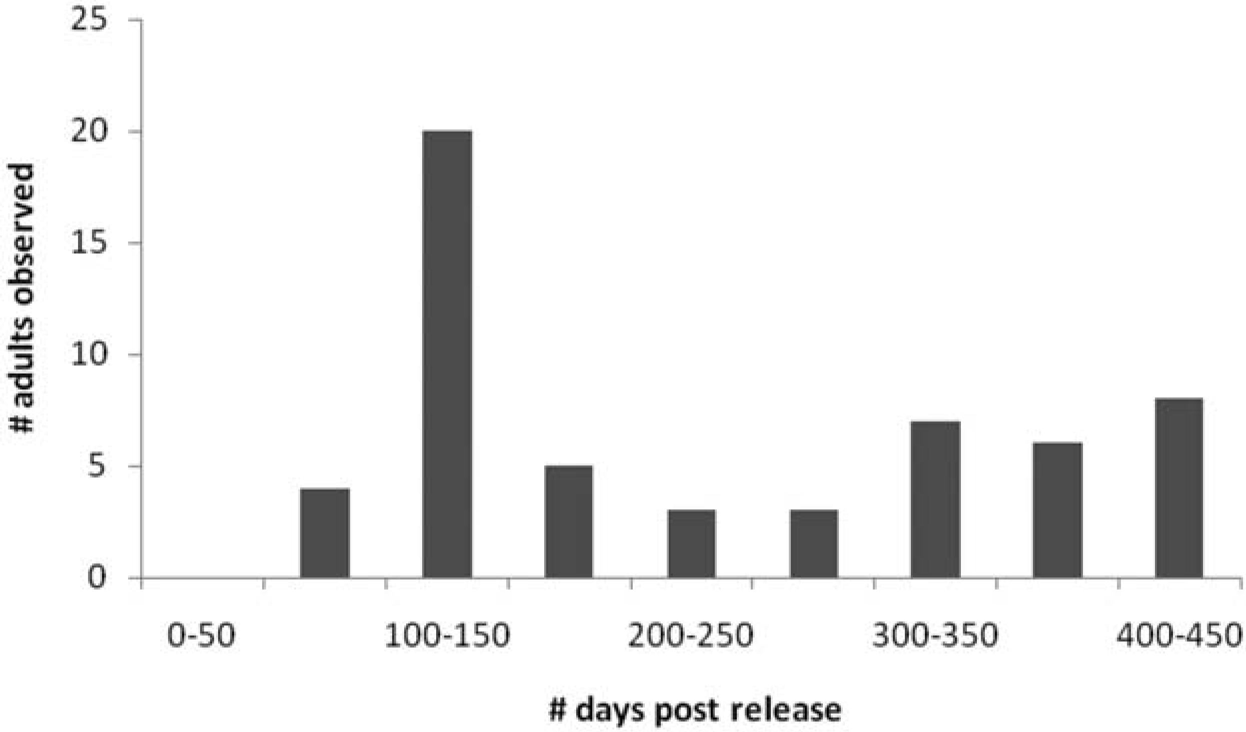

Figure 6. Number of adult frogs observed at different times (days) post-release.

(i.e., *Galaxia maculatus*, *Anguilla australis*) and introduced poeciliid fish (i.e., Gambusia *Gambusia holbrooki* and/or One-spot Livebearer *Phalloceros caudimaculatus*) were found in the ponds that were furthest downstream and had two-way water connections between them (i.e., ponds 3, 4, 5, 9; Fig. 2). Two ponds that were upstream of this first group of ponds contained both native fish species, but lacked the introduced Gambusia (i.e., ponds 1 & 2; Fig. 2). Three ponds that were higher still and isolated from all the other ponds were found to be fish-free (i.e., ponds 10, 14 & 15; Fig. 2). Ponds that have subsequently been built have included three isolated and fish-free ones (i.e., ponds 11, 16L, 16R; Fig. 2) and one, with a two-way connection to pond 9, that has contained introduced fish (i.e., pond 12; Fig. 2).

Survival of bell frog tadpoles to metamorphosis was low in ponds with fish and higher in fish-free ponds. During the 10 weeks following the initial tadpole release, bell frog tadpoles were captured during net sweeps of fish-free ponds (mean = 0.57 ± 0.12 tadpoles; n=20), but not in ponds containing either just native fish or both native and introduced fish (n=20 for each). This difference was highly significant (P=0.000; ANOVA). No bell frog tadpoles were subsequently captured during the next 6-month period in any of the ponds. During the 12-month period after the initial release, the average number of metamorphs observed per pond per survey was low for the ponds with fish (mean=0.034±0.024, n=58 for both kinds of ponds with fish) and significantly (P=0.03, ANOVA) higher for the fish-free ponds (mean 0.17±0.08, n=58). As frogs may move between ponds after metamorphosis, their observed distribution across the ponds was not considered for either immatures or adults.

Subsequently, we only released tadpoles into fish-free ponds and avoided ponds with introduced fish. On two occasions since the initial tadpole release we released tadpoles into the two ponds that contained native fish but lacked introduced fish (i.e., ponds 1 & 2; Table 1). All other releases were into fish-free ponds (i.e., ponds 14, 15, 16L, 16R; Table 1).

Following subsequent tadpole releases into the two ponds with just native fish (i.e., Nov 1999, Feb 2001; Table 1), bell frog tadpoles were not captured and metamorphs were not observed. During the 10-week periods after these releases, net sweep samples were carried out at these ponds on 10 occasions without yielding any bell frog tadpoles. During the 12-month periods after these releases, frog surveys were carried out at these ponds on 46 occasions without any bell frog metamorphs being observed.

Successive tadpole releases into fish-free ponds

Successive tadpole releases into fish-free ponds from the 1997/1998 to the 2003/2004 breeding season showed no significant differences in terms of tadpoles captured but were decreasingly successful in terms of observed metamorphs and immatures. Considering ponds 14 and 15, which were the principal fish-free ponds used over this time period (Table 1), and omitting the autumn tadpole releases (i.e., 24/03/1999 & 19/03/2004) and the release just prior to the drying-up of these ponds (i.e., 22/12/2000), there was no significant effect of breeding season on the average number of tadpoles captured within 70 days of tadpole release (i.e., P's>0.05, Regression Analyses). No tadpoles were observed after the releases of tadpoles during the 2002/2003 and 2003/2004 breeding seasons. However, with the same constraints, the average numbers of metamorphs observed within 104 days of tadpole release and immatures observed within 200 days of tadpole release decreased significantly with successive breeding seasons (Figs. 7 & 8; P's<0.05, Regression Analyses).

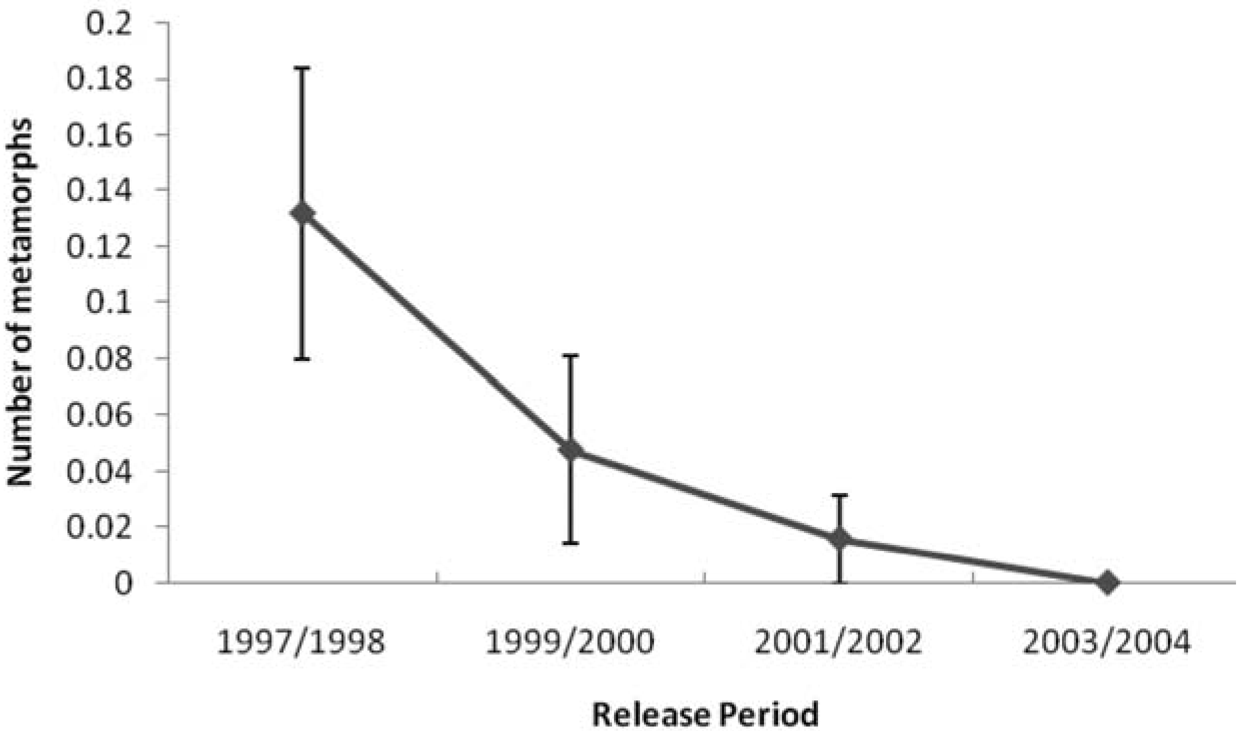

Figure 7. Average number (± s.e.) of metamorphs observed vs successive breeding seasons.

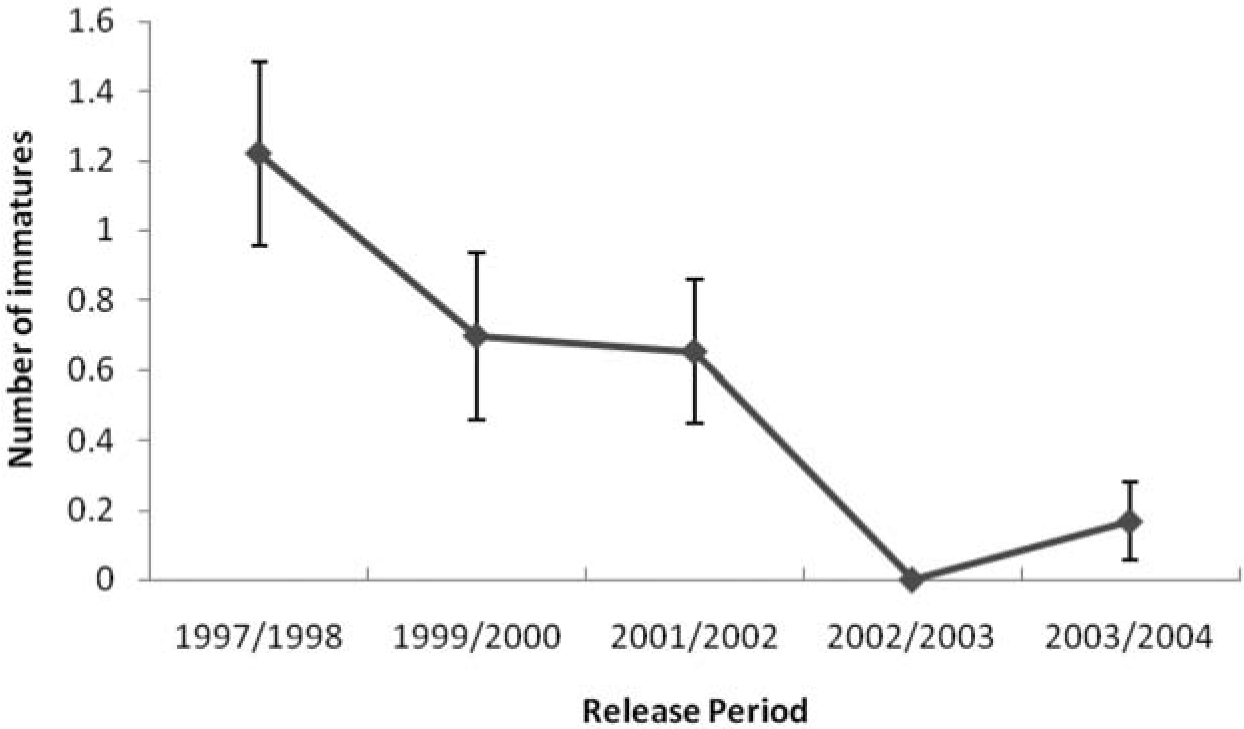

Figure 8. Average number (± s.e.) of immature frogs observed vs successive breeding seasons.

Changes to fish-free ponds between 1997/1998 and 2003/2004 breeding seasons

Between the 1997/1998 and 2003/2004 breeding seasons, the two fish-free ponds, 14 and 15, acquired increasing amounts of aquatic vegetation, became colder during spring and summer, and were ultimately considered unsuitable for growth and development of bell frog tadpoles. A comparison of photographs of pond 15 taken in December 1997 and October 2002 from close to the same location shows a large increase in aquatic vegetation during the intervening period (Figs. 9 & 10). Between the 1997/1998 and 2002/2003 breeding seasons the average spring and summer water temperatures decreased significantly with successive breeding seasons (Fig. 11; P's<0.05, Regression Analyses). Water measurements were not taken in these ponds during the 2003/2004 season, but these ponds appeared similar in this season and the one before (G. Pyke pers. obs.). Based on the work by Penman (1998), we considered that the average water temperatures in these two ponds had been too low for growth and development of bell frog tadpoles during spring since the second breeding season (i.e., since 1998/1999) and during summer since the 2000/2001 season (Fig. 11).

Pond water temperatures following pond modification and development in late 2003

Partial removal of aquatic vegetation from ponds 14 and 15 made little apparent difference to water temperatures in these ponds, but average water temperatures have been higher in the new fish-free ponds (i.e., 16L and 16R), and high enough for growth and development of bell frog tadpoles. Following partial removal of aquatic vegetation from ponds 14 and 15 in November

Figure 9. Pond 15 in December 1997.

Figure 10. Pond 15 in October 2002.

2003, autumn water temperatures in these ponds have averaged 16.0°C (n=10) which is lower (contrary to expectation) but not significantly different from the autumn average in these ponds during the previous two years (19.7° C, n=2; $P>0.05$, Mann-Whitney U-test).

Since development of ponds 16L and 16R, their water temperatures have averaged 1.8°C higher than the water temperatures in ponds 14 and 15 ($P<0.05$; paired t-test) and, during spring, have averaged 23.1°C (n=2). Though not measured, water temperatures in these ponds during summer should be at least this high and therefore high enough for bell frog tadpoles to grow and develop.

Adult frogs

Captures of sexable bell frogs have indicated that equal numbers of males and females have survived to this age, some males have reached maturity in about three months post metamorphosis, and some females have reached maturity in about 12 months. Over the course of the project, we captured a total of 45 bell frog individuals that could be sexed (i.e., SVL>48 mm), of which there were 23 females and 22 males. The proportion male (0.49) is not significantly different from 0.5 ($P>0.05$, normal approximation to binomial).

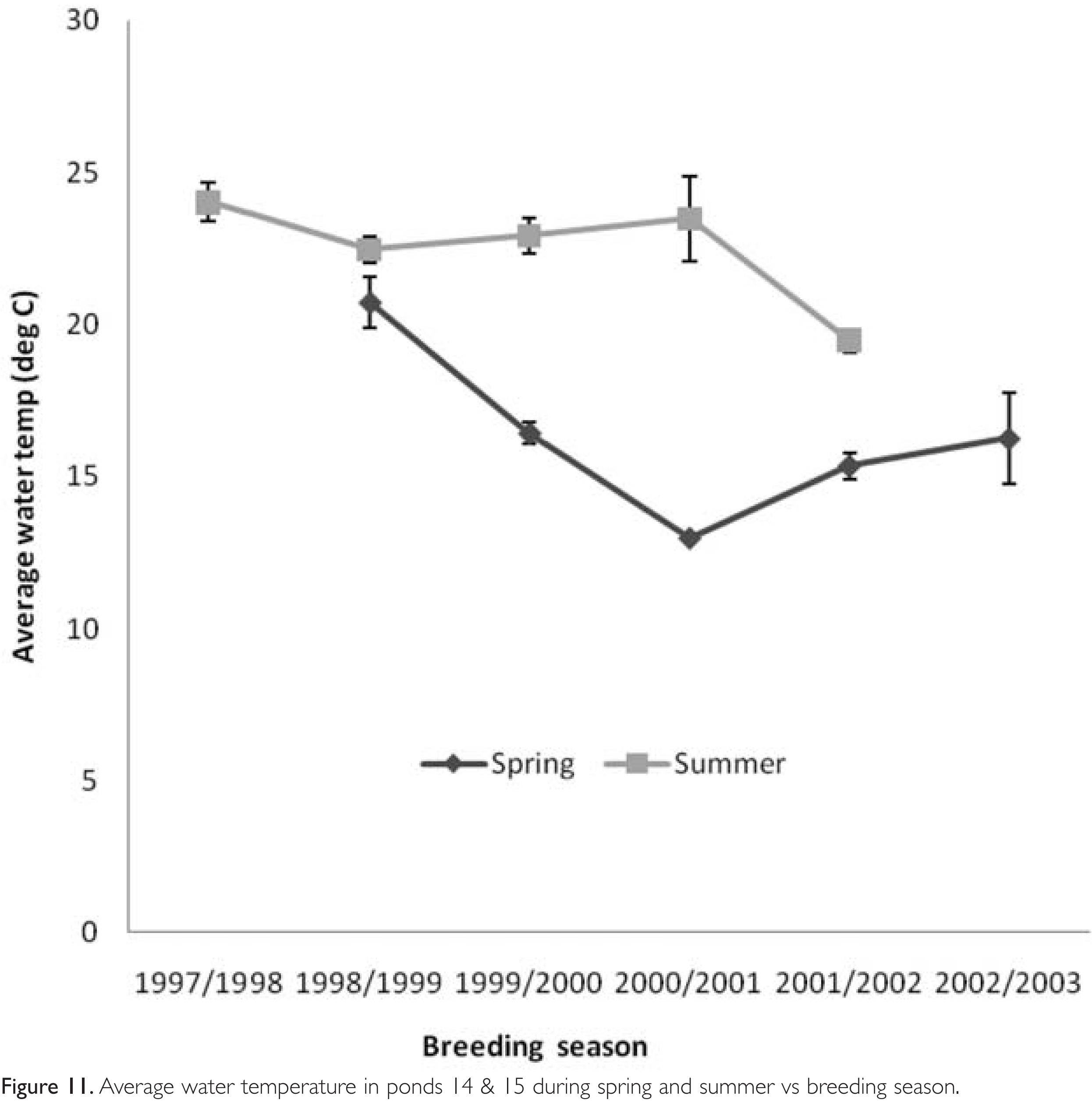

Figure 11. Average water temperature in ponds 14 & 15 during spring and summer vs breeding season.

Four adult males were captured during the period April-May 1998 and would have been no more than about three months old (i.e., following initial tadpole release in January 1998 and subsequent metamorphosis during January-March 1998). Of the captured females, 12 had reached maturity (i.e., SVL>65 mm) and six of these were captured during the period January-March 1999 and were therefore no more than about 12 months old post metamorphosis.

Bell frogs that were microchipped showed low rates of recapture. A total of 17 bell frogs were captured at least twice, with most (i.e., 71%) showing intervals of less than 10 weeks between first and last capture and the longest such interval being only about six months (i.e., 189 days). No bell frog is known to have reached the minimum size to be microchipped (i.e., 40 mm) and to then have been captured during more than one breeding season.

Disease

No sign of disease was observed amongst tadpoles and frogs at the study site. During the monitoring program, large numbers of tadpoles and frogs of a number of frog species (*Limnodynastes peronii*, *Crinia signifera*, *Litoria fallax*, *Litoria peronii*), were captured and observed, without any being observed to show signs of disease infection such as lethargic behavior or skin rashes.

Discussion

The introduction program for the Green and Golden Bell Frog at Long Reef Golf Course has had partial success, but must overall be considered unsuccessful as it has not resulted in the establishment of a self-sustaining population of this species. Some of the released tadpoles of this species metamorphosed into frogs, some of these immature frogs grew and developed into adults, and a few males were recorded calling. However, breeding by these introduced animals has not been recorded, and, in the absence of continuing tadpole releases, the number of bell frogs has declined to zero. The observed numbers of adult frogs have been low relative to the numbers of tadpoles released, but this would be expected as the average clutch size is relatively large in this species and mortality between tadpole and adult frog would therefore presumably be very high.

Success with this program has apparently been limited by fish, time of tadpole release and water temperature, requiring ongoing changes to the program. Tadpole releases have been preferentially carried out into fish-free ponds after discovery of fish presence and their apparent negative effect on tadpole survival. Tadpoles, metamorphs and immatures were observed after tadpole releases that took place during spring or summer, but none of these life stages were observed following autumn releases. Spring or summer releases were therefore targeted. Additional ponds with warmer water were developed after observations indicated that water temperatures in existing ponds were too low for growth and development of bell frog tadpoles.

Success with the program has also apparently been limited by the numbers of tadpoles available for release, and the lack of tadpoles for spring/ summer release since the 2003/2004 breeding season has prevented evaluation of the new warmer ponds. The maximum number of tadpoles released per season was only 2000 (i.e., 2000/2001 season; Table 1), which is fewer than the average size of a single bell frog clutch and small in relation to the potential output of the captive breeding program that included 20-30 adult females. During one season (i.e., 2002/2003), this captive breeding program yielded only 62 tadpoles for release at Long Reef. Following the development of the additional, warmer ponds in late 2003, there has been one tadpole release in autumn 2004 and none since then.

Disease seems unlikely to have been a significant factor in affecting the outcomes of this program. Tadpoles were screened for disease before release and were therefore presumably disease-free. No sign of disease has been observed in any of the frogs or tadpoles at the site. However, since disease has been linked with frog declines in a number of situations, it must always be considered potentially important.

Further prospects for the program are limited, but not zero. There are presently no captive breeding populations based on the natural population at Rosebery, which has been the agreed source for tadpoles released at Long Reef. However, it has recently been discovered that some bell frog individuals remain in suburban gardens at Rosebery, breeding by this species has been recently recorded and attempts have been made to enhance the available breeding habitat for the species through the development of suitable garden ponds. It might, therefore, be possible to translocate bell frog eggs or tadpoles from these ponds to the ponds at Long Reef.

Although unsuccessful, our program provides a number of guidelines for similar programs in the future. We recommend that future translocations of Green and Golden Bell Frog tadpoles should be carried out during spring or summer and should target ponds that are warm and fish-free. We also recommend that steps are taken to ensure that sufficient numbers of tadpoles are available through captive breeding to meet the requirements of any program based on their release into the wild.

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